Coastal Engineering Technical Note

ATLANTIC COAST WATER LEVEL PREDICTIONS

PURPOSE: To inform coastal engineers of the availability of the Waterways Experiment Station WIS Report 7, "Atlantic Coast Water-Level Climate," (Ebersole, 1982), and to provide guidance on its use. The initial distribution of this report is only one per district and division because of the report's large size.

BACKGROUND: Selection of a design water level for use in coastal projects is often a difficult task when there is a lack of reliable historic data. Use of a design level which is easily exceeded may result in failure of the project, while a conservative selection of design water level results in additional project cost. Therefore it is to the coastal engineer's advantage to be able to predict the probability of a water level being exceeded at a specific site. This probability must include the combined effects of astronomical tides and storm surge. For example, the occurrence of a storm surge concurrent with a spring high tide will produce a substantial water level rise, but will have a small probability of occurring.

ATLANTIC COAST WATER LEVEL STATISTICS: The Wave Information Study (WIS) has developed water level statistics for selected sites on the U.S. Atlantic Coast. The raw data used in the study are comprised of historical water-level records from 20 National Ocean Survey (NOS) tidal reference stations. The 20 sites are listed below.

Sites of Available Water-Level Predictions

Eastport, ME	New London, CT	Hampton Roads, VA
Bar Harbor, ME	Montauk Pt., NY	Southport, NC
Portland, ME	Willets Pt., NY	Charleston, SC
Seavey Island, ME	The Battery, NY	Fort Pulaski, GA
Boston, MA	Sandy Hook, NJ	Mayport, FL
Woods Hole, MA	Atlantic City, NJ	Miami Beach, FL
Newport, RI	Lewes, DE	

The reference datum for these statistics is the *yearly mean sea level* at each tide station.

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14. ABSTRACT
Selection of a design water level for use in coastal projects is often a difficult task when there is a lack of reliable historic data. Use of a design level which is easily exceeded may result in failure of the project while a conservative selection of design water level results in additional project cost. Therefore it is to the coastal engineer’s advantage to be able to predict the probability of a water level being exceeded at a specific site. This ncr-o-b-a-b-i-l-i-t-vJ must include the combined effects of astronomical tides and storm surge. For example, the occurrence of a storm surge concurrent with a spring high tide will produce a substantial water level rise, but will have a small probability of occurring.

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The water level probabilities are for combined astronomical tide and storm surge which are assumed to be statistically independent. It is very important to note that these statistics do not include storm surges due to tropical storms (i.e., hurricanes). Future reports will deal with water levels due to combined astronomical tides and extreme tropical storm surges.

PRODUCTS OF WIS REPORT 7: WIS Report 7 presents four statistical water level products for each of the 20 selected sites. Recommendations are given in Report 7 for extrapolating these data to sites between stations. Each of the four products is illustrated and discussed below, and numerical examples are given where appropriate.

1. Monthly and Yearly Mean Sea Levels. Figure 1 illustrates how the monthly and yearly values of mean sea level have fluctuated over the past 60 years in Charleston, South Carolina. The variation of the yearly mean is attributed to tropical and extratropical storm events. Figure 1 seems to illustrate a trend of a long term rise in sea level at Charleston; and, if such were the case, it may be important in determining design criteria for long-life coastal projects. The mean sea level axis refers to elevation above the tide gage zero reference. *However, the analyses in Report 7 did not delve into the stability of or accuracy of the datum plane (or tide gage zero reference); consequently, no conclusions should be drawn from Report 7 data regarding the rate or even the veracity of a postulated sea level rise. Close inspection of Figure 1 reveals that data from 1948 to the present do not, in themselves, reveal an obvious tendency for a sea level rise.

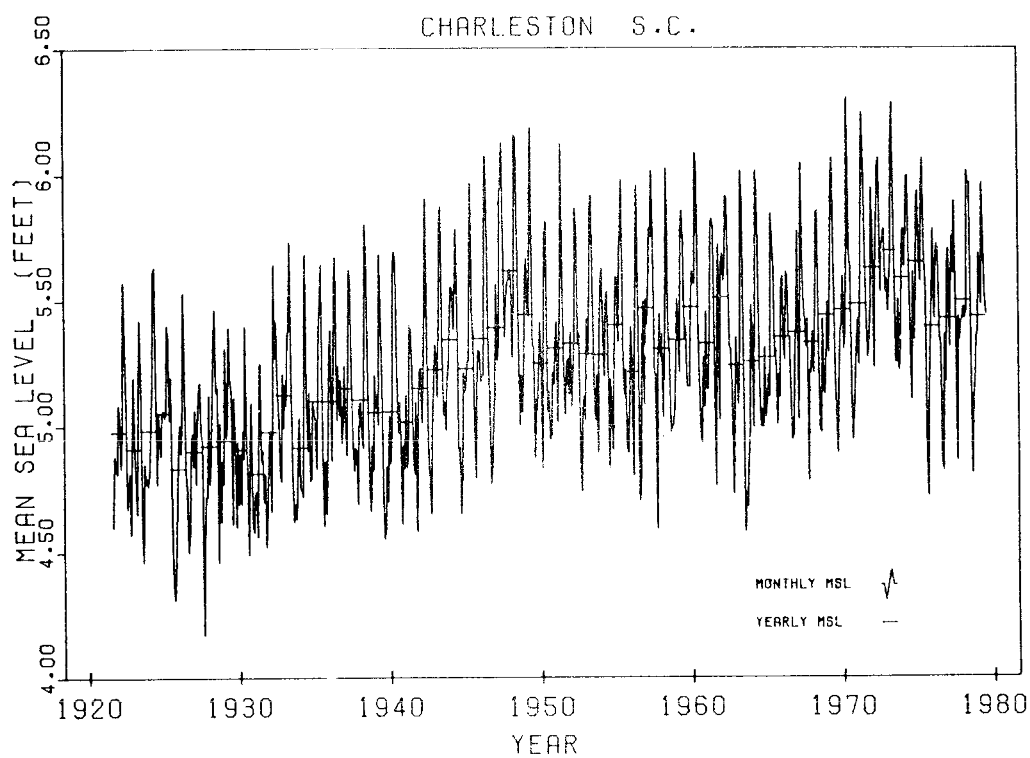

Figure 1: Example of Mean Sea Levels.

2. Probability Density and Cumulative Distribution Statistics. These tables provide the monthly and yearly water level probability statistics for each station. Each table gives interval probability, P(X), and the cumulative probability, F(X), for astronomical tides, storm surge, and combined tide and surges. The elevation reference (X) on these tables has units of feet. Report 7 cautions about using the portion of the probability functions relating to large positive elevations. Figure 2 (yearly statistics) illustrates the format of these tables and is used for the following example.

MAYPORT FLA.

YEARLY STATISTICS

ASTRONOMICAL TIDE — MEAN 0.00 STND DEV 1.67

I	X	P(X)	F(X)
1	-4.00	0.	0.
2	-3.90	0.	0.
3	-3.80	0.	0.
4	-3.70	0.0000	0.0000
5	-3.60	0.0001	0.0001
6	-3.50	[illegible]	[illegible]
7	-3.40	[illegible]	0.0011
8	-3.30	[illegible]	[illegible]
9	-3.20	[illegible]	[illegible]
10	-3.10	[illegible]	[illegible]
11	-3.00	[illegible]	0.0110
12	-2.90	[illegible]	[illegible]
13	-2.80	[illegible]	[illegible]
14	-2.70	[illegible]	[illegible]
15	-2.60	[illegible]	0.0455
16	-2.50	[illegible]	[illegible]
17	-2.40	[illegible]	[illegible]
18	-2.30	0.0131	[illegible]
19	-2.20	[illegible]	[illegible]
20	-2.10	[illegible]	[illegible]
21	-2.00	[illegible]	[illegible]
22	-1.90	[illegible]	[illegible]
23	-1.80	[illegible]	[illegible]
24	-1.70	[illegible]	[illegible]
25	-1.60	[illegible]	[illegible]
26	-1.50	[illegible]	[illegible]
27	-1.40	[illegible]	[illegible]
28	-1.30	[illegible]	[illegible]
29	-1.20	[illegible]	[illegible]
30	-1.10	[illegible]	[illegible]
31	-1.00	0.0170	[illegible]
32	-0.90	0.0170	[illegible]
33	-0.80	[illegible]	[illegible]
34	-0.70	0.0159	[illegible]
35	-0.60	[illegible]	[illegible]
36	-0.50	[illegible]	[illegible]
37	-0.40	[illegible]	[illegible]
38	-0.30	[illegible]	[illegible]
39	-0.20	[illegible]	[illegible]
40	-0.10	[illegible]	[illegible]
41	0.	[illegible]	[illegible]
42	0.10	[illegible]	[illegible]
43	0.20	[illegible]	[illegible]
44	0.30	[illegible]	[illegible]
45	0.40	0.0151	[illegible]
46	0.50	[illegible]	[illegible]
47	0.60	[illegible]	[illegible]
48	0.70	0.0160	[illegible]
49	0.80	0.0160	[illegible]
50	0.90	[illegible]	[illegible]
51	1.00	0.0177	[illegible]
52	1.10	0.0180	[illegible]
53	1.20	0.0201	[illegible]
54	1.30	[illegible]	[illegible]
55	1.40	[illegible]	[illegible]
56	1.50	[illegible]	[illegible]
57	1.60	[illegible]	[illegible]
58	1.70	[illegible]	[illegible]
59	1.80	[illegible]	[illegible]
60	1.90	[illegible]	[illegible]
61	2.00	[illegible]	[illegible]
62	2.10	[illegible]	[illegible]
63	2.20	[illegible]	[illegible]
64	2.30	[illegible]	[illegible]
65	2.40	[illegible]	0.9353
66	2.50	[illegible]	[illegible]
67	2.60	[illegible]	[illegible]
68	2.70	[illegible]	[illegible]
69	2.80	[illegible]	[illegible]
70	2.90	[illegible]	[illegible]
71	3.00	0.0051	[illegible]
72	3.10	[illegible]	[illegible]
73	3.20	[illegible]	[illegible]
74	3.30	[illegible]	0.9953
75	3.40	0.0015	[illegible]
76	3.50	[illegible]	0.9978
77	3.60	[illegible]	0.9986
78	3.70	0.0005	0.9991
79	3.80	0.0004	0.9995
80	3.90	0.0003	0.9998
81	4.00	0.0001	0.9999

STORM SURGE — MEAN-0.01 STND DEV 0.43

I	X	P(X)	F(X)
1	-4.00	0.	0.
2	-3.90	0.	0.
3	-3.80	0.	0.
4	-3.70	0.	0.
5	-3.60	0.	0.
6	-3.50	0.	0.
7	-3.40	0.	0.
8	-3.30	0.	0.
9	-3.20	0.	0.
10	-3.10	0.	0.
11	-3.00	0.	0.
12	-2.90	0.	0.
13	-2.80	0.	0.
14	-2.70	0.	0.
15	-2.60	0.	0.
16	-2.50	0.	0.
17	-2.40	0.	0.
18	-2.30	0.	0.
19	-2.20	0.	0.
20	-2.10	0.	0.
21	-2.00	0.0000	0.0000
22	-1.90	0.0000	0.0000
23	-1.80	0.0001	0.0001
24	-1.70	0.0001	0.0002
25	-1.60	0.0002	0.0004
26	-1.50	0.0003	0.0007
27	-1.40	0.0006	0.0013
28	-1.30	0.0010	0.0023
29	-1.20	0.0015	0.0038
30	-1.10	0.0026	0.0064
31	-1.00	0.0047	0.0110
32	-0.90	0.0077	0.0187
33	-0.80	0.0133	0.0320
34	-0.70	0.0237	0.0557
35	-0.60	0.0352	0.0909
36	-0.50	0.0517	0.1426
37	-0.40	0.0689	0.2115
38	-0.30	0.0828	0.2943
39	-0.20	0.0931	0.3874
40	-0.10	[illegible]	[illegible]
41	0.	[illegible]	[illegible]
42	0.10	[illegible]	[illegible]
43	0.20	[illegible]	[illegible]
44	0.30	0.0558	0.8151
45	0.40	0.0510	0.8661
46	0.50	0.0397	0.9058
47	0.60	0.0281	0.9338
48	0.70	0.0204	0.9543
49	0.80	0.0152	0.9695
50	0.90	0.0104	0.9799
51	1.00	0.0070	0.9869
52	1.10	0.0049	0.9918
53	1.20	0.0030	0.9948
54	1.30	0.0020	0.9968
55	1.40	0.0012	0.9980
56	1.50	0.0007	0.9988
57	1.60	0.0004	0.9992
58	1.70	0.0003	0.9995
59	1.80	0.0003	0.9998
60	1.90	0.0001	0.9999
61	2.00	0.0001	0.9999
62	2.10	0.0000	1.0000
63	2.20	0.0000	1.0000
64	2.30	0.	1.0000
65	2.40	0.	1.0000
66	2.50	0.	1.0000
67	2.60	0.	1.0000
68	2.70	0.	1.0000
69	2.80	0.	1.0000
70	2.90	0.	1.0000
71	3.00	0.	1.0000
72	3.10	0.	1.0000
73	3.20	0.	1.0000
74	3.30	0.	1.0000
75	3.40	0.	1.0000
76	3.50	0.	1.0000
77	3.60	0.	1.0000
78	3.70	0.	1.0000
79	3.80	0.	1.0000
80	3.90	0.	1.0000
81	4.00	0.	1.0000

TOTAL WATER LEVEL — MEAN-0.02 STND DEV 1.73

I	X	P(X)	F(X)
1	-6.00	0.	0.
2	-5.80	0.	0.
3	-5.60	0.	0.
4	-5.40	0.	0.
5	-5.20	0.0000	0.0000
6	-5.00	0.	0.0000
7	-4.80	0.	0.0000
8	-4.60	0.0000	0.0000
9	-4.40	0.0000	0.0001
10	-4.20	0.0001	0.0002
11	-4.00	0.0004	0.0006
12	-3.80	0.0009	0.0015
13	-3.60	0.0021	0.0035
14	-3.40	0.0044	[illegible]
15	-3.20	0.0077	[illegible]
16	-3.00	0.0125	[illegible]
17	-2.80	0.0191	0.0473
18	-2.60	0.0259	0.0732
19	-2.40	0.0312	0.1045
20	-2.20	0.0350	[illegible]
21	-2.00	0.0375	0.1769
22	-1.80	[illegible]	0.2158
23	-1.60	0.0377	0.2535
24	-1.40	0.0368	0.2903
25	-1.20	0.0359	0.3262
26	-1.00	0.0337	0.3599
27	-0.80	0.0336	0.3936
28	-0.60	0.0307	0.4243
29	-0.40	0.0307	0.4550
30	-0.20	0.0299	[illegible]
31	0.	0.0306	0.5154
32	0.20	0.0309	0.5463
33	0.40	0.0303	0.5766
34	0.60	0.0323	0.6090
35	0.80	0.0350	0.6439
36	1.00	0.0378	0.6818
37	1.20	0.0396	0.7214
38	1.40	0.0406	0.7619
39	1.60	0.0402	0.8021
40	1.80	0.0394	0.8415
41	2.00	0.0362	0.8777
42	2.20	0.0309	0.9086
43	2.40	0.0262	0.9348
44	2.60	0.0203	0.9551
45	2.80	0.0153	0.9704
46	3.00	0.0112	0.9816
47	3.20	0.0074	0.9890
48	3.40	0.0048	[illegible]
49	3.60	0.0030	[illegible]
50	3.80	0.0017	0.9986
51	4.00	0.0007	0.9993
52	4.20	0.0004	0.9997
53	4.40	0.0002	0.9999
54	4.60	0.0001	1.0000
55	4.80	0.0000	1.0000
56	5.00	0.0000	1.0000
57	5.20	0.	1.0000
58	5.40	0.	1.0000
59	5.60	0.	1.0000
60	5.80	0.	1.0000
61	6.00	0.	1.0000

I - INTERVAL NUMBER　　X - INTERVAL CENTER VALUE
P(X) - PROBABILITY MASS FUNCTION　　F(X) - CUMULATIVE DISTRIBUTION FUNCTION

Figure 2: Example of Water Level Probabilities.

* * * * * * * * * * * * * * * * *

Required: Find the probability that the total water level will exceed 1.6 feet above mean sea level in any one year at Mayport, Florida.

Solution: The probability, $F(h < 1.6)$, that the water level will be below 1.6 feet is found from Figure 2 under the "Total Water Level" heading. For $X = 1.60$, $F(h < 1.6) = 0.8021$.

Therefore the probability that the water level will be above 1.6 feet is

$F(h > 1.6) = 1 - F(h < 1.6) = 1 - 0.8021 = 0.1979$ or about 19.8 %.

* *

Linear interpretation of values is performed in the same fashion as in CETN-I-13 (Calculating Tidal Elevation Probabilities).

3. Duration Statistics. These statistics are featured on two plots for each station, one for the total water level and one for the storm surge. Duration is the length of time a water level will remain above a certain level once that level has been exceeded. An example is given in Figure 3 where the lower line is the average duration and the upper line is the maximum duration. For example, when the total water level at Boston exceeds 4.0 feet, it will remain above this level for about 2.6 hours on the average and for about 6.5 hours at the maximum. This information is useful for cases where a certain water level can be tolerated for a specified length of time.

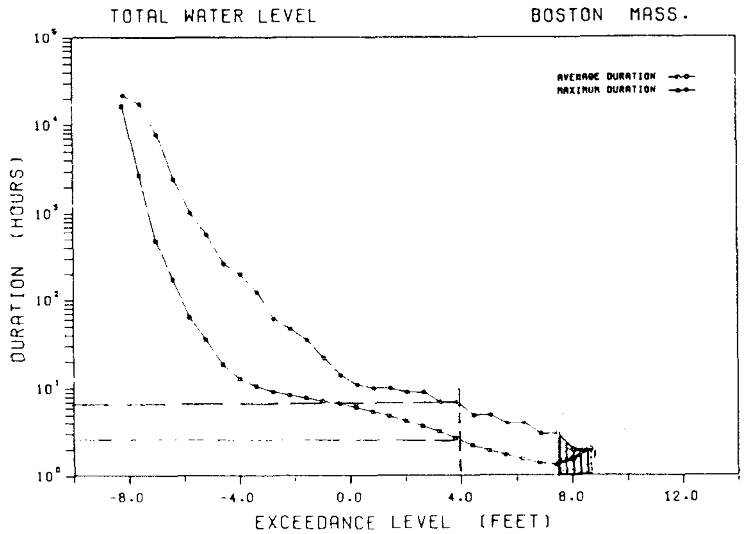

Figure 3: Example of Duration Plots

Report 7 points out that the maximum duration values might be slightly conservative, and cautions about interpreting results from the shaded region of the plot (see Figure 3).

4. Extreme Storm Surge Data. A theory was developed for extreme storm surge probability prediction using the monthly maxima of surge measured at each tidal reference station. Each station has 13 figures, one for the yearly maxima and 12 for the monthly extremes. An example is given in Figure 4, where a return period of 10 years corresponds to an extreme storm surge of about 3 feet.

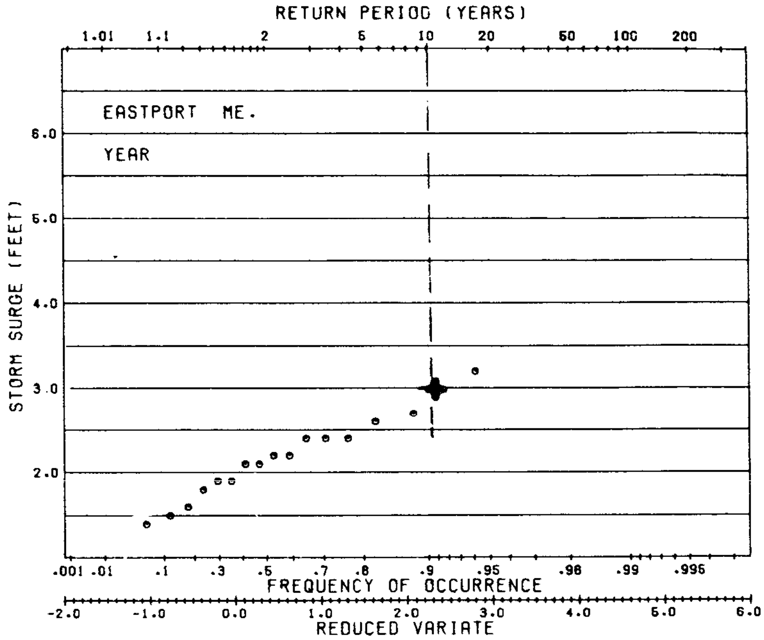

Figure 4: Example of Extreme Storm Surge Probability.

Report 7 discusses the development of these figures, and the possible sources of error. A method is given to determine the confidence limits, and these should be used when determining extreme storm surges from these tables. Work is in progress on a WIS Report that will contain statistics of large storm surges due to both tropical and extratropical storm. Therefore, the extreme storm surge data presented in Report 7 should be considered as interim design guidance.

ESTIMATES FOR OTHER ATLANTIC COAST SITES: The joint probability distribution of tides and surges for locations other than the 20 sites given in the table can be computed using the method suggested by Harris (1981). First, the distribution of tidal elevation probabilities at the desired location is generated from the known probability distribution of a nearby station. This involves multiplying the known distribution by the ratio of the mean tide ranges at the two sites. An example of this procedure is given in CETN I-13. Second, the surge probability distribution at a specific site can be given as a simple linear interpretation between two adjacent sites for which statistics are known. This can be done with reasonable accuracy since the storm surge statistics vary only slightly from station to station. Finally, the joint tide and storm surge probability distribution is obtained using the procedure given in Harris (1981) on pages 82-85.

REFERENCES:

EBERSOLE, B. A., "Atlantic Coast Water-Level Climate," WIS Report 7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, April 1982.

HARRIS, D. L., "Tides and Tidal Datum in the United States," SR-7, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Virginia, February 1981.

U.S. ARMY, CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, "Calculating Tidal Elevation Probabilities," CETN-I-13, Fort Belvoir, Virginia, 1981.